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ABSTRACT

This study examined whether analogy or means-ends strategies (heuristics) would be used to solve geometric puzzle-like problems, which were generated by a microcomputer. The subjects in the two-group experiment were undergraduate students enrolled in an introductory psychology course at Potsdam College (New York). One group of subjects learned about analogy problem solving. The other served as control. The computer was used as a conveyence for the treatments being examined. An original computer program was used to collect, organize, and manage the data generated by subjects, as they worked on puzzle-like problems. The results indicated that subjects preferred to use means-ends strategies to solve the computer-generated problems. The findings verify the conclusions of earlier means-ends studies in which devices other than computers were used. It was suggested that further research include the special attributes of computers to train means-ends and analogies heuristics in problem solving. Thirty-six references are provided, as well as five figures which illustrate the problems and correct and incorrect responses. (PK)

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Problem-Solving Research With Computers

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Abstract

This study examined whether analogy or means-ends strategies (heuristics) would be used to solve geometric puzzle-like problems, which were generated by a microcomputer.

The subjects in the two group experiment were undergraduate students enrolled in an introductory psychology course at Potsdam College, State University of New York. One group of subjects learned about analogy problem solving. The other served as control. The computer was used as a conveyence for the treatments being examined.

An original computer program was used to collect, organize, and manage the data generated by subjects, as they worked on puzzle-like problems. The data were analyzed by ANOVA procedures to determine which strategies were more likely to be chosen during the problem-solving process.

The results indicated that subjects preferred to use means-ends strategies to solve the computer-generated problems. The findings verify the conclusions of earlier means-ends studies in which devices other than computers were used. It was suggested that further research include the special attributes of computers to train means-ends and analogies heuristics in problem solving.

Introduction

The mental (cognitive) processes used during problem solving have been the object of a substantial amount of study in recent years. This was not the case, some forty years ago, when psychologists first realized that common puzzle-like problems could not be solved by many people (Luchins, 1942; Duncker, 1945; Polya, 1945). At that time, what mattered was whether or not the problem was solved and how many errors were made. That research approach has changed. A more current view is that knowledge of of the cognitive processes used to solve a problem is most important (Bruner et al, 1956; Newell and Simon, 1972; Greeno, 1974; Hays and Simon, 1977; Hinsley et al, 1977; Reed, 1977).

A premise of this research is that the study of puzzle-like tasks can contribute to an understanding of problem-solving mechanisms, and to cognitive processes in general. Much modern work on problem solving has been based on how adults solve puzzle-like problems (Polson & Jeffries, 1982).

The reasons why the puzzles have been utilized in other research studies is that:

(1) Puzzle-like problems are concise. Minimal information is needed to solve them.

(2) No extensive training procedures are needed to prepare the subjects. Puzzles are omnipresent. They appear in schools,

and in almost every other facet of the culture. It would be rare to find individuals who had no experience solving puzzles.

(3) They vary in levels of difficulty. For example, the four puzzle problems, chosen for inclusion in this study, did not appear to be too difficult for college-level students. In addition, the puzzles were knowledge lean. This meant that the problems could be solved without extensive study of subject matter from an academic discipline.

(4) Puzzle-like problems can provide an experimenter with a substantial amount of information about the solution attempt. The choices that subjects make should indicate something about how they organize and decide during problem solving. Furthermore, when the domain of answers is small, whether or not the problems are solved becomes less important than how the problems are solved. However, unless the puzzles are extremely difficult, they will be solved, invariably.

(5) Finally, puzzles are fun to work with. In most cases, subjects of all abilities find they have a game-like quality. Even lower ability subjects typically like them because the puzzles seem to be less structured, and to be more discovery oriented (Clark, 1982).

An original computer program was used in the present study to generate the four puzzle-like problems. They were related to similar problems used in recent investigations by the principal investigator (Licht, 1983,1985,1986). Another original computer

program was used to collect the data generated by the subjects as they worked on the puzzle-like problems. The data were organized systematically in order to describe the intellectual processes used by subjects as they rendered judgments, and made decisions in solving the problems. These puzzle solutions were analyzed to determine which strategies were used during the problem-solving process. Two strategies were investigated. Both belong to a class of decision making called heuristics.

What is meant by heuristic strategies has been described by Polya (1945), and Bruner et al. (1956). Heuristic strategies refer to a pattern of decisions that ensure certain forms of outcomes, and ensure against certain others. They are inferred from the individual choices that problem solvers make during the problem-solving process. The crucial element in determining the heuristics is a discernable pattern of the choices.

As a test for heuristic strategies in the present study, an empirical design was derived from one reported in a number of recent experiments (Licht, 1983,1985,1986). These designs were, in turn, the product of attempts to expand the work of Atwood and Polson (1976), and Jeffries et al. (1977), who attempted to find the differences between good and poor problem solvers. They tried to link the problem solvers to the cognitive processes, or decison-making strategies that they employed. The design of the present study included a way to discriminate between the more

commonly employed means-ends strategies, and the more illusive analogy heuristic. The former is a short cut strategy and uses a backward search process. The latter describes a strategy that is preferred by better problem solvers, and teachers of problem solving, because it involves an understanding of the underlying structure of problems (Jeffries, 1979; Greeno, 1980).

When a problem solver adopts an analogy strategy, that person uses the solution to an earlier problem to help solve a subsequent problem. The design and sequence of analogy-problem solving generally follows these steps (Reed, 1977):

(1) The subjects must notice that the present problem is analogous to the previous problem;

(2) They must remember how they solved the earlier problem;

(3) They must be able to translate the previous solution into steps that apply to the original problem.

The problem solver using the analogy strategy is showing an understanding of the underlying structure of the problem, and is able to make connections, and to transfer this knowledge to another problem. This explains why such a strategy is considered optimal. Often, this strategy helps problem solvers to resolve more problems, use fewer choices in decision making, and spend less time arriving at the correct solutions.

A more commonly used heuristic is called the means-ends strategy. This is a selective search during which problem

solvers look at only the parts of problems that are likely to produce a solution. In those cases, the problem solvers repeatedly compare two different stages of the problems. They compare their current or present state with the desired state, and try to reduce the difference. That search is sequential, and rarely leads to a knowledge of the underlying structure (Newell & Simon, 1972; Gelman & Gallistel, 1978; Siegler, 1981; Sweller & Levine, 1982).

Although the analogy strategies have been recognized as the more efficient problem-solving strategies, it should also be noted that means-ends procedures often end in solution, when the domain of answers in the problem set is very small. That was the case in this study.

Statement of the Problem

Will subjects choose analogy strategies to solve a set of related geometric puzzle-like problems when they are generated by microcomputer? Or, will the subjects use another heuristic, the means-ends strategies to solve the problems?

Method

Sample

The sample consisted of 40 college undergraduates (21 females and 19 males) enrolled in introductory psychology at

Potsdam College, State University of New York, Potsdam, New York. All of the subjects volunteered in order to receive extra credit in the course.

Apparatus

The instruments that were used in the test condition were Apple IIe personal computers (PC's). The PC's were equipped with video display terminals (VDT), and were located in the Potsdam College microcomputer laboratory. Subjects were given brief instructions in the use of the PC's, if they had not used them before.

Materials

The puzzle-like problems consisted of a series of seven vertical or horizontal lines; each was approximately one-half inch from its neighbor. The spacing between the lines made the lines appear to be the boundaries for six columns or rows. Figure 1 illustrates the lines generated for trials 1-4. In trials 1 and 2, the lines bordered columns. In trials 3 and 4, the lines bordered rows.

During each trial, a number of rows or columns would darken or appear to fill in. A set of numbers accompanied and labeled the filled-in regions. These numbers were permutations of the numbers 123; that is, there are six different ways that these

numbers may be represented: 123, 132, 213, 231, 321, and 312. Figures 2-5 show examples of each of the four trials. The beginning numbers were randomly selected for each problem.

Subjects

From the sample pool of 42 subjects, 21 were randomly selected to be included in the experimental treatment group; that is, they were taught analogy strategies by text and in class. The subjects were assigned to study a chapter on problem solving from the course text in psychology (Crider et al., 1986). In addition, the subjects were expected to attend two lectures. Analogical problem-solving was emphasized in the text material and during the lectures.

The members of the control group (not exposed to analogies strategies) were randomly selected from the same pool of possible subjects. Although 21 subjects were selected originally, only 19 participated in the experiment because two subjects withdrew so late that they could not be replaced.

Procedures

The members of the control group worked with the puzzle-like problems before the text material was assigned to the experimental group members, and well in advance of the two lectures. It may be assumed that these subjects were not alerted

to the use of analogy, or means-ends strategies prior to the testing period.

The experimental treatment group members were tested on the puzzle-like problems within 24 hours after they had attended the second lecture. Attendence records indicated that all subjects attended both lectures.

Test Conditions

All subjects were assigned their own PC's, and were given a floppy diskette containing the computer programs. The program generated all of the instructions; displayed each problem; and, recorded all of the responses and latencies.

First, subjects were asked to identify themselves by entering their student numbers. Then, they were instructed in the rules of the puzzle-like problems (called games). They were told that the goal of the games was to pick the numbers that would cause the rows or columns to darken so that a black rectangle would appear on the display screen (VDT). Next, they were shown a sample problem and its solution. These words appeared on the display screen:

> "This screen is only partially filled in. The numbers associated with the partly filled columns are 123. Another set of numbers from the following list will solve the problem: 123 132 213 231 312 321. The correct answer is 312."
>
> Then all of the columns filled in and the display screen

appeared as a black rectangle. The narration continued on the display screen:

> "If you enter the correct numbers, all of the columns or rows will appear to fill in, and the screen will resemble a black rectangle. Then, you will be told that you have solved the problem, and a new problem will appear. If you choose an incorrect number, the screen will only be partly filled in. The screen wll clear then, and you will be advised to try again. You will be allowed up to ten choices. However, the major goal of the game is to select the correct numbers in the fewest attempts. So, try to choose the right numbers quickly. But, do not get discouraged if your first few attempts aren't correct. Press any key when you are ready to start."

The computer program contained a random-number generator that determined how many columns or rows would be filled for each of the problems. That same random-number generator also set the prompt numbers that accompanied the filled-in regions. While the list of numbers (permutations of 123) remained constant, the randomly selected numbers and the prompts were different each time. In addition, the order and direction, of the columns and the rows that were being filled, was changed for each of the four trials. In the first trial, the columns were filled from right-to-left; in the second trial, the columns were filled in the reverse direction, from left-to-right; and in the last two trials the rows were filled from top-to-bottom, and from bottom-to-top.

The correct answer could be derived by thinking of the columns or rows as part of a ribbon that was connected at both

ends, as a circle would be. Then, the underlying structure of the problems would become clear--they consisted of a repeating series of lines and numbers, much like a neon sign that keeps showing the same sequence of six numbers and geometric designs, in apparent animation.

Dependent variables

The primary dependent variable was the strategy (heuristic) the subjects employed to solve the puzzle-like problems. This was a response measure that was inferred from the number of choices made during the problem-solving process. Individual data were examined to determine which of two heuristics the subjects were using: either analogy, or means-ends strategies.

An analogy strategy, indicative of an understanding of the underlying structure was inferred if the subject needed four or fewer choices to solve successive problems. This operational definition was derived from recent experimental work that described a subject using a logical approach to problem solving (Licht, 1986).

If more than four choices were required to solve two or more successive problems, it was inferred that subjects were using means-ends heuristics--solving each of the problems separately, as if they were not related to each other, and not in the same same family of problems.

The secondary dependent variables were: (1) total number of choices to solution, and (2) latency of responses measured in seconds.

Statistical treatment

The chi square, a nonparametric statistic, was used to determine whether the frequencies of either analogy or means-ends strategies could be attributed to random variation. Chi square was used because the data of the two strategies were estimated from successive choices; thus, the calculations were based on qualitative data. What was examined here was whether or not the data were distributed within two different categorical classifications, and were independent of one another. To test for those conditions, the two-way classification chi-square was deemed appropriate. If the chi-square was found to be significant, the phi-square statistic would then be applied to measure the strength of the preference for strategy selection. The phi-square is really the Pearson r^2 and is interpreted as such (Myers & Grossen, 1974).

An analysis of variance (ANOVA) procedure for a two-way classification design was utilized for the secondary-dependent variables--total choices and latencies. The ANOVA procedure was appropriate because the data were continuous, and each subject in each case contributed exactly one score to the data.

Results

After chi-square was applied, it may be observed that the cell results departed significally from what was expected-- ($P<0.05$, Table I).

-Insert Table I about here-

This indicates that subjects in both conditions preferred to use means-ends problem solving strategies. The interpretation of phi-square is that 91% of the variance of the problem-solving strategies is accounted for on the basis of this preference for means-ends. This is a strong and significant finding. It confirms studies of strategy preference in non-computer environments when puzzle-like problems are encountered (Jeffries, 1979; Greeno, 1980; Siegler, 1981). It appears as if analogy stategies are not utilized in problem solving as often as means-ends, even when subjects are trained to use them.

The two-way ANOVA procedure conducted on the four puzzle problem choices indicated no significant differences between groups (Table II).

-Insert Table II about here-

This finding is consistent with studies that show no transfer or carry over of problem-solving abilities into daily

life (Hunt, 1982). The results also confirm the earlier reports which indicated that inefficient problem-solving strategies are more likely to be chosen in such circumstances (Luchins, 1942; Duncker, 1945; Polya, 1945).

The two-way ANOVA that considered latency data between the problems showed significant differences ($P<0.0003$, Table III). Each of the problems, in succession, required less time to solve.

-Insert Table III about here-

The time-efficiencies means and standard deviations may be found in Table IV.

-Insert Table IV about here-

There is an observable relation between the mean times needed to solve each of the problems. The experimental group means showed that less time was needed to solve each succeeding problem. The control group means showed that less time was needed for trials 2 and 3; but, trial 4 required more time than either of trials 2 or 3.

Discussion

The primary aim of this research was to determine whether subjects who learned about analogy strategies in a classroom lecture setting with appropriate text material would use these strategies to solve puzzle-like problems that were generated by a computer. The performance data showed that subjects preferred to use means-ends strategies, a less efficient problem-solving heuristic. This failure to demonstrate transfer of analogy strategies is consistent with findings in which underlying structure analysis is not utilized in puzzle-like situations, and in which computers were not used as conveyences (Jeffries, 1979; Greeno, 1980; Siegler, 1981).

The results were also in agreement with the theory that transfer of learning most often occurs when the training conditions more closely match the testing conditions; transfer is less likely to occur when the conditions are very different (Rubinstein, 1975; Detterman & Sternberg, 1982; Glaser, 1984). In this case, the question is: should computers be used in training as well as in the testing conditions?

The results also raise other questions: Why do problem solvers use means-ends strategies so often? Is it because the process places less strain on a problem solver? This study has shown that as long as the domain of answers is small, most problems will be solved by the means-ends strategy. Only

two of the 160 puzzle-like problems were unsolved. Perhaps, more emphasis should be placed on reducing the number of solutions to problems and their parts; keeping the domain of answers small, so that the means-ends heuristic may be used more frequently, could be a worthy goal both in and out of school type situations.

In conclusion, it is not too surprising that so many students selected a less efficient problem-solving strategy. Current media investigations, including those that involve computers, suggest that students often incorrectly assess the extent to which the instructional method will allow them the most efficient use of their effort. It has been recommended that the special attributes of computers be used to train cognitive skills of problem solving for students who need them (Clark, 1975; Levie & Dickie, 1973; Salomon, 1979). Those special attributes include animation, branching programming tactics, and slow motion or zooming into details of a complex field. Research involving such attributes could contribute to improved instructional design, and to advances in theory development of problem-solving heuristics.

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Table I- Chi Square Summary Table- Individuals' Strategies Inferred From Number of Choices During Problem Solving.

df	sample size	chi square	significance	phi square
$\chi^2(3,$	$N= 40) = 3.67,$		$p<.05$	$\phi=0.91$

Expected (E) and Observed (O) Strategies for each Treatment Group

		Strategies	
		Analogy	Means-Ends
Subjects	Experimental	E = 11 O = 8	E = 10 O = 13
	Control	E = 10 O = 6	E = 9 O = 13

Table II- Analyses of Puzzle-Like Problem Choices

Analysis of Variance Summary Table- Problem-Solving Choices

Source	df	Variance Estimate	F	Probability
Groups	1	6.40	1.24	0.26
Problems	3	4.39	0.85	0.47
Interaction	3	8.60	1.67	0.17
Residual	152	5.16		
Total	159	5.22		

Mean Efficiency Scores And Standard Deviations for Each Treatment Group

Groups	N	$\bar{X}$	S.D.
Experimental	76	3.42	2.32
Control	84	3.82	2.24

Mean Efficiency Scores and Standard Deviations For Each Problem

Problems	N[a]	$\bar{X}$	S.D.
No. 1		3.67	2.06
No. 2		4.05	2.71
No. 3		3.25	2.08
No. 4		3.55	2.24

[a] N = 40 for each problem.

Table III-Analyses Of Latencies For Puzzle-Like Problem Solutions

Analysis of Variance Summary Table-Latencies for Puzzle Solutions

Source	df	Variance Estimate	F	Probability
Groups	1	1011.55	2.09	0.14
Problems	3	3619.67	7.48	0.0003 *
Interaction	3	1164.66	2.41	0.0681
Residual	152	483.67		
Total	159	559.01		

* F <.05

Table IV- The Means and Standard Deviations of Time Efficiencies.

Mean Time Efficiencies and Standard Deviations for Each Treatment Group.

Groups	N	$\bar{X}$	S.D.
Experimental	76	31.37	27.40
Control	80	26.33	19.50

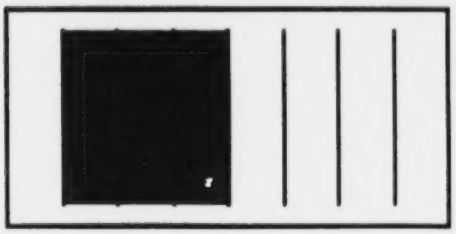
Mean Time Efficiencies in Seconds for Each Puzzle-Like Problem.

Problem	N	$\bar{X}$	S.D.
No. 1	40	41.08	31.96
No. 2	40	31.28	22.96
No. 3	40	20.42	14.16
No. 4	40	22.13	15.18

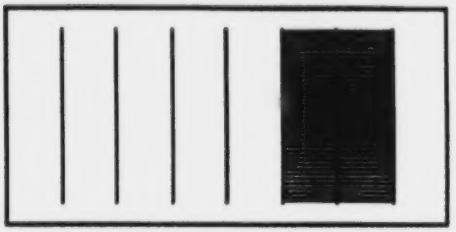
Mean Time Efficiencies in Seconds for Treatment Groups and Puzzle-Like Problem Combinations

Combination*	N	$\bar{X}$	S.D.
E & No. 1	19	48.11	35.65
E & No. 2	19	39.00	27.36
E & No. 3	19	20.16	14.67
E & No. 4	19	18.21	14.85
C & No. 1	21	34.71	27.54
C & No. 2	21	24.29	15.70
C & No. 3	21	20.67	14.04
C & No. 4	21	25.67	16.25

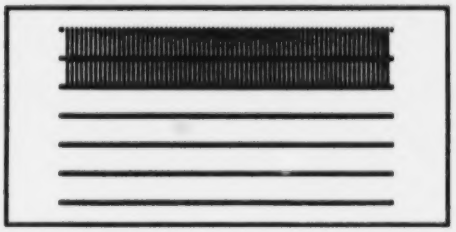
* E= Experimental group and C= Control group.



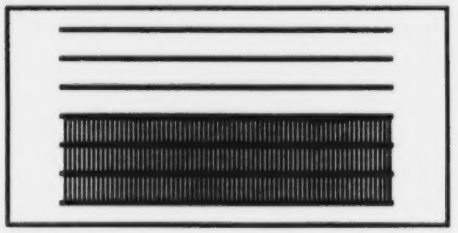
A. Trial 1.



B. Trial 2.



C. Trial 3.



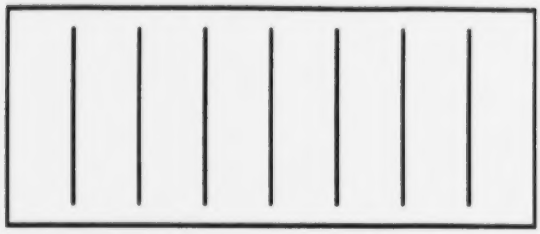
D. Trial 4.

Figure 1. Regions were filled in from different directions for each trial. A: In trial 1, columns were filled in from left-right. B: In trial 2, columns were filled in from right-left. C: In trial 3, rows were filled top-bottom. D: In trial 4, rows were filled from bottom-top.

A. Start of Problem - Trial 1

Columnar division of the screen is explained. Columns are identified by permutations of 123.

for example...



123 132 213 231 312 321

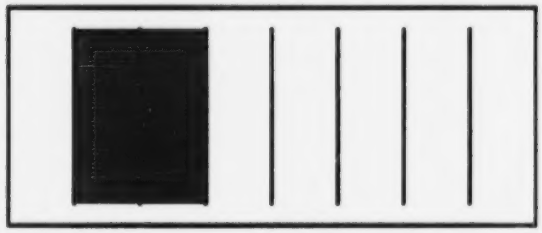
B. 132 Fills to Here

Prompting information is supplied and illustrated.

What permutation of 123 would fill the entire screen?

C. Incorrect. 321 Fills to Here

Choice of 321 would produce this result..



D. Correct. 231 Fills the Screen

Choice of 231 would completely fill the screen, indicating that the shifted column nomenclature has been correctly deduced.

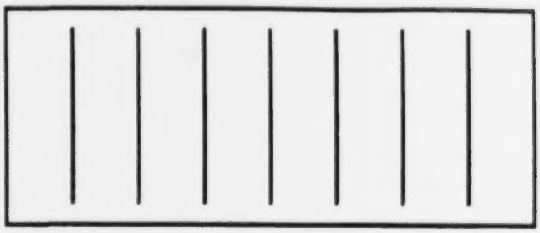
312 321 123 132 213 231

Figure 2. Lines and filled-in regions appearing during trial 1.
A: Region cleared at start of trial.
B: Columns filled in response to prompt 132.
C: An incorrect choice fills less of the screen.
D: The correct choice fills the entire screen

A. Start of Problem - Trial 2

Columnar division of the screen is explained. Columns are identified by permutations of 123.

for example...

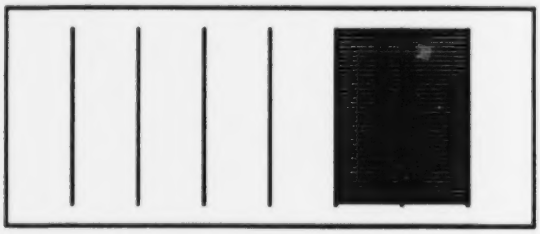


123 132 213 231 312 321

B. 132 Fills to Here

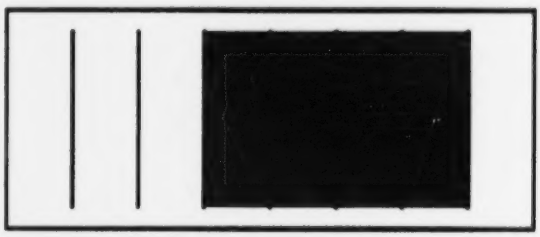
Prompting information is supplied and illustrated.

What permutation of 123 would fill the entire screen?



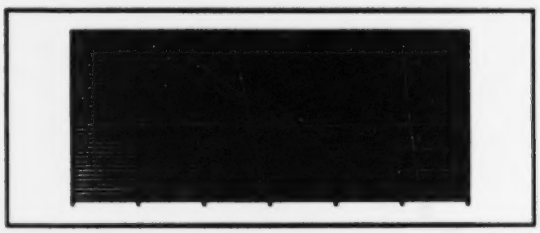
C. Incorrect. 231 Fills to Here

Choice of 231 would produce this result..



D. Correct. 321 Fills the Screen

Choice of 321 would completely fill the screen, indicating that the column nomenclature has been correctly deduced, as well as the change in order from left to right.



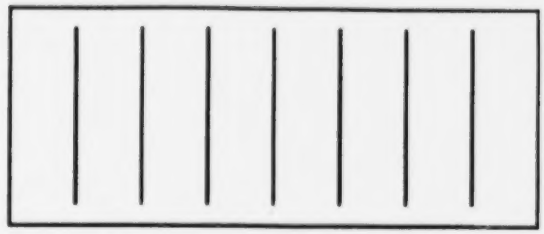
321 312 231 213 132 123

Figure 3. Lines and filled-in regions appearing during trial 2.
A: Region cleared at start of trial.
B: Columns filled in response to prompt 231.
C: An incorrect choice fills some of the screen.
D: The correct choice fills the entire screen

A. Start of Problem - Trial 3

Columnar division of the screen is explained. Columns are identified by permutations of 123.

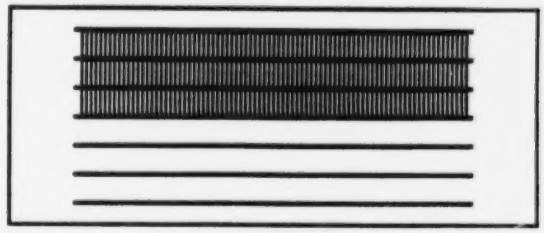
for example...



123 132 213 231 312 321

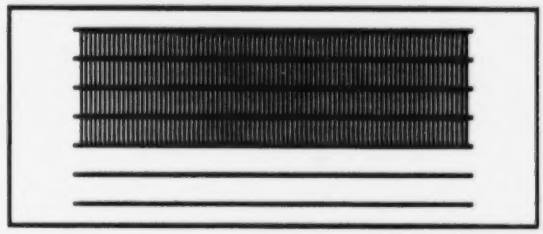
B. 213 Fills to Here

Prompting information is supplied and illustrated. If 213 fills three rows, then what permutation of 123 would fill the entire screen?



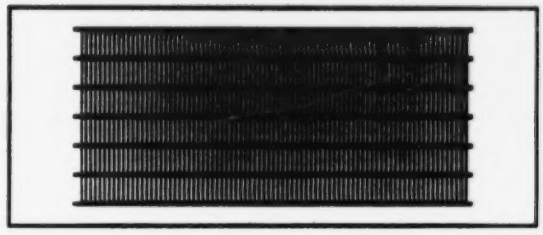
C. Incorrect. 231 Fills to Here

Choice of 231 would produce this result..



D. Correct. 321 Fills the Screen

Choice of 321 would completely fill the screen, indicating that the top to bottom orientation has been correctly deduced.



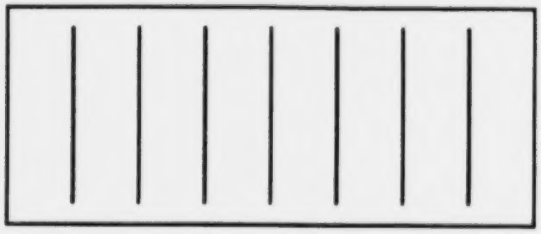
123
132
213
231
312
321

Figure 4. Lines and filled-in regions appearing during trial 3.
A: Region cleared at start of trial.
B: Rows filled in response to prompt 213.
C: An incorrect choice fills some of the screen.
D: The correct choice fills the entire screen

A. Start of Problem - Trial 4

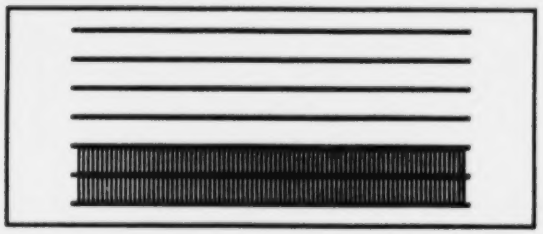
Columnar division of the screen is explained. Columns are identified by permutations of 123.

for example...



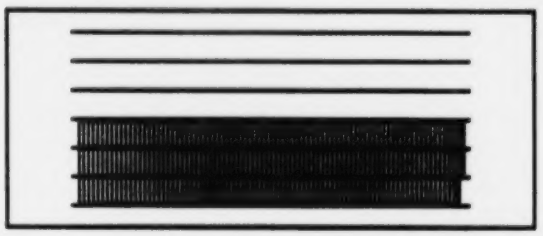
B. 213 Fills to Here

Prompting information is supplied and illustrated. If 213 fills these two rows, then what permutation of 123 would fill the entire screen?



C. Incorrect. 231 Fills to Here

Choice of 231 would produce this result..



D. Correct. 123 Fills the Screen

Choice of 123 would completely fill the screen, indicating that the bottom-top orientation and the change in origin have been correctly deduced.

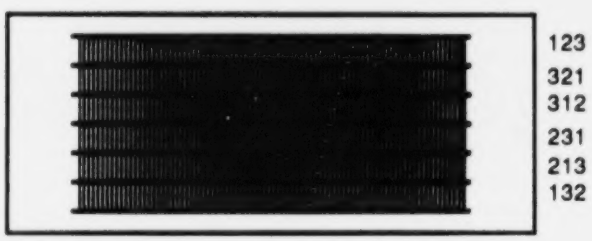


Figure 5. Lines and filled-in regions appearing during trial 4.

A: Region cleared at start of trial.

B: Rows filled in response to prompt 213.

C: An incorrect choice fills some of the screen.

D: The correct choice fills the entire screen